2 - WATERSHED LOADING MODELS

A watershed runoff and loading model (HSPF) was developed for the Christina River Basin to estimate the amount of nutrients and oxygen demanding substances introduced to the receiving streams during rainfall-runoff events. In addition, an urban storm water runoff model (XP-SWMM) was developed by the City of Wilmington and was used to estimate combined sewer overflow (CSO) flows and loads to local receiving waters.

2.1 HSPF Model Overview

The Hydrologic Simulation Program—Fortran (HSPF), is a U.S. EPA supported model for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. The HSPF model uses information such as the time history of rainfall, temperature and solar radiation; land surface characteristics such as land-use patterns; and land management practices to simulate the processes that occur in a watershed. The result of this simulation is a time history of the quantity and quality of runoff from an urban or agricultural watershed. Flow rate, sediment load, and nutrient and pesticide concentrations are predicted. HSPF includes an internal database management system to process the large amounts of simulation input and output. HSPF includes the source code, executable version, user's guide, and technical support. The HSPF model incorporates the watershed-scale Agricultural Runoff Model (ARM) and Non-Point Source (NPS) models into a basin-scale analysis framework that includes pollutant transport and transformation in stream channels.

The Christina River Basin drains 565 square miles in Pennsylvania, Delaware, and Maryland. Water from the basin is used for recreation, drinking-water supply, and to support aquatic life. The Christina River Basin includes four main watersheds: Brandywine Creek, Red Clay Creek, White Clay Creek, and Christina River. Brandywine Creek is the largest of the watersheds and drains an area of 327 square miles. Water quality in some parts of the Christina River Basin is impaired and does not support designated uses of the streams.

A multi-agency water-quality management strategy included a modeling component to evaluate the effects of point and nonpoint-source contributions of nutrients and suspended sediment on stream water quality. To assist in nonpoint-source evaluation, four independent models, one for each of the four main watersheds of the Christina River Basin, were developed and calibrated using the HSPF modeling framework.

The HSPF models simulate streamflow, suspended sediment, nitrogen, phosphorus, BOD, water temperature, and dissolved oxygen. For the models, the Christina River Basin was subdivided into 70 reaches. Ten different pervious land uses and two impervious land uses were selected for simulation. Land-use areas were determined from 1995 land-use data. The predominant land uses in the basin are forested, agricultural, residential, and urban.

The hydrologic component of the model was run at an hourly time step and calibrated using streamflow data for eight U.S. Geological Survey (USGS) streamflow measurement stations for a period covering four water years from October 1, 1994 to October 1, 1998. Daily precipitation data for three National Oceanic and Atmospheric Administration (NOAA) gages and hourly data for one NOAA gage were used for model input. More detailed descriptions of the HSPF models developed for the Christina River Basin can be found in Senior and Koerkle (2003a, 2003b, 2003c, and 2003d).

2.2 XP-SWMM Model Overview

The City of Wilmington has developed a model (XP-SWMM) to simulate stormwater flows and CSO events in the city's sewer collection system. XP-SWMM is a link-node model that performs hydrology, hydraulics, and water quality analysis of stormwater and wastewater drainage systems including sewage treatment plants, water quality control devices, and best management practices (BMPs). XP-SWMM can be used to model the full hydrologic cycle from stormwater and wastewater flow and pollutant generation to simulation of the hydraulics in any combined system of open and/or closed conduits with any boundary conditions. Typical XP-SWMM applications include predicting combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs), interconnected pond analysis, open and closed conduit flow analysis, major/minor flow analysis, design of new developments, and analysis of existing stormwater and sanitary sewer systems.

XP-SWMM uses a self-modifying dynamic wave solution algorithm. Like all implicit solutions, which solve for the unknown values at a given time simultaneously, XP-SWMM is not Courant-limited. However, XP-SWMM uses the Courant number as a guide, to prevent numerical attenuation that can occur if excessively large time steps are used. This is important in models where pumps are involved or in urban systems where steeply rising hydrographs, requiring responses in seconds or fractions of a second will predominate, or where checks are being made against empirical procedures like the FHWA inlet control scheme for culverts. XP-SWMM will use small time steps when required and larger time steps when appropriate.

XP-SWMM has three computational modules. There is a stormwater module for hydrology and water quality generation, a wastewater module for generation of wastewater flows including Storage/Treatment for BMP and water quality routing, and a hydrodynamic hydraulics module for the hydraulic simulation of open and closed conduit wastewater or stormwater systems.

Hourly flow rates at each of the city's 38 CSO outfalls were calculated by XP-SWMM for the 1994-1998 calibration period based on hourly rainfall measured at New Castle County Airport and Porter Reservoir. Water quality was monitored at three CSO locations (CSO 25, CSO 4b, and the 11th Street Pump Station) for storm events on October 27, 2003, December 17, 2003, and November 4, 2004. Event mean concentrations (EMCs) were estimated for nutrients and oxygen demanding substances (see Tables 2-1a, b, c, and d). The monitoring included 20-day CBOD (CBOD20), 5-day CBOD (CBOD5), dissolved organic carbon (DOC), total organic carbon (TOC), ammonia nitrogen (NH3-N), nitrite+nitrate nitrogen (NOxN), total Kjeldahl nitrogen (TKN), total nitrogen (TN), dissolved orthophosphate (DOrthP), total phosphorus (TP), and total suspended solids (TSS). The EMCs were used in conjunction with the CSO flow rates to estimate daily loads for each CSO outfall. The CSO flows and loads were then input to the EFDC receiving water model to simulate the impact on nutrient and dissolved oxygen concentrations in the tidal Christina River, lower Brandywine Creek, and Little Mill Creek. The annual average baseline and TMDL nutrient loads from each of the CSO discharges for the calibration period are tabulated in Appendix B. The locations of the CSOs are shown in Appendix B, Figure B-1.

Table 2-1a. Storm monitoring at Wilmington CSO 4b

Date	Time	CBOD20 mg/L	CBOD5 mg/L	DOC mg/L	TOC mg/L	NH3-N mg/L	NOxN mg/L	TKN mg/L	TN mg/L	DOrthP mg/L	TP mg/L	TSS mg/L
STORET code –>		80087	80082	00681	00680	00610	00630	00625	****	00671	00665	00530
Storm Event #1												
10/27/2003	11:40	14.62	11.70	6.6	9.1	0.362	0.969	1.400	2.369	0.004	0.238	298
10/27/2003	12:10	13.60	5.82	2.9	3.7	0.137	0.248	0.275	0.523	0.020	0.320	278
10/27/2003	12:40	10.20	5.64	6.1	6.2	0.189	0.502	0.644	1.146	0.100	0.219	195
10/27/2003	13:10	14.48	7.85	5.9	7.1	0.238	0.831	1.080	1.911	0.126	0.270	177
10/27/2003	13:40	13.98	7.65	6.8	8.3	0.244	1.070	1.210	2.280	0.141	0.219	75
10/27/2003	14:10	13.50	10.60	7.3	8.9	0.238	1.290	1.370	2.660	0.159	0.216	32
Storm Event #2												
12/17/2003	09:00	16.20	9.20	4.9	6.8	0.403	0.627	2.650	3.277	0.203	0.388	35
12/17/2003	09:30	16.10	8.65	4.7	6.2	0.480	0.855	2.790	3.645	0.180	0.382	34
12/17/2003	10:00	23.80	12.80	6.8	8.4	4.520	1.210	4.830	6.040	0.222	0.546	25
12/17/2003	10:30	16.20	10.60	5.9	6.1	0.504	1.360	3.060	4.420	0.192	0.416	17
12/17/2003	11:00	12.10	8.18	5.5	6.0	0.486	1.710	2.610	4.320	0.138	0.306	19
12/17/2003	11:30	10.60	6.86	5.0	6.2	0.357	1.970	1.950	3.920	0.112	0.194	19
Storm Event #3												
11/4/2004	13:33	25.10	13.10	22.9	24.4	0.206	0.391	1.250	1.641	0.308	0.489	174
11/4/2004	14:03	28.40	15.20	18.3	20.2	0.154	0.337	0.937	1.274	0.256	0.376	31
11/4/2004	14:33	27.40	15.00	20.6	22.8	0.145	0.540	1.060	1.600	0.268	0.386	14
11/4/2004	15:03	24.50	15.60	22.2	23.5	0.113	0.748	1.080	1.828	0.250	0.314	11
11/4/2004	15:33	23.60	13.60	22.5	29.1	0.197	0.710	1.870	2.580	0.218	0.407	27
Event Mean Concentrations												
EMC		17.90	10.47	10.29	11.94	0.528	0.904	1.769	2.673	0.170	0.334	86

Table 2-1b. Storm monitoring at Wilmington CSO 25

Date	Time	CBOD20 mg/L	CBOD5 mg/L	DOC mg/L	TOC mg/L	NH3-N mg/L	NOxN mg/L	TKN mg/L	TN mg/L	DOrthP mg/L	TP mg/L	TSS mg/L
STORET code –>		80087	80082	00681	00680	00610	00630	00625	****	00671	00665	00530
Storm Event #1												
10/27/2003	11:00	13.88	13.88	11.8	14.4	0.325	0.516	1.270	1.786	0.234	0.296	32
10/27/2003	11:30	14.76	14.76	10.3	11.6	0.294	0.503	1.050	1.553	0.286	0.397	33
10/27/2003	12:00	7.83	5.36	3.8	4.3	0.136	0.215	0.392	0.607	0.113	0.178	51
10/27/2003	12:30	12.14	12.14	70.5	80.0	0.421	0.634	3.070	3.704	1.870	1.620	39
10/27/2003	13:30	14.10	14.10	10.6	11.6	0.352	0.820	1.900	2.720	0.249	0.450	26
10/27/2003	14:00	14.26	14.26	10.8	12.0	0.455	1.160	2.480	3.640	0.354	0.642	15
Storm Event #2												
12/17/2003	08:45	15.00	9.48	6.3	6.6	0.350	0.547	1.850	2.397	0.202	0.102	27
12/17/2003	09:15	28.30	19.60	9.1	10.2	0.500	0.839	3.140	3.979	0.317	0.296	22
12/17/2003	09:45	28.76	28.76	40.8	44.6	3.720	1.030	5.500	6.530	1.560	1.580	14
Storm Event #3												
11/4/2004	13:20	28.50	14.90	15.4	18.3	0.476	0.272	1.990	2.262	0.277	0.505	42
11/4/2004	13:50	27.74	15.30	14.0	15.2	0.559	0.315	2.220	2.535	1.000	1.100	39
11/4/2004	14:20	28.00	14.10	17.2	19.1	0.606	0.422	2.630	3.052	0.385	0.637	19
11/4/2004	14:50	26.10	15.10	16.4	19.6	0.712	0.513	3.180	3.693	0.436	0.706	16
Event Mean Concentrations												
EMC		19.95	14.75	18.24	20.58	0.685	0.599	2.359	2.958	0.560	0.655	29

Table 2-1c. CSO Storm monitoring at Wilmington 11th Street Pumping Station (CSO 3)

Date	Time	CBOD20 mg/L	CBOD5 mg/L	DOC mg/L	TOC mg/L	NH3-N mg/L	NOxN mg/L	TKN mg/L	TN mg/L	DOrthP mg/L	TP mg/L	TSS mg/L
STORET code –>		80087	80082	00681	00680	00610	00630	00625	****	00671	00665	00530
Storm Event #1												
10/27/2003	11:20	11.76	11.76	23.5	29.6	4.040	0.467	7.250	7.717	0.262	1.470	454
10/27/2003	11:50	10.88	10.88	9.5	11.9	3.070	1.100	3.820	4.920	0.433	0.520	71
10/27/2003	12:10	10.88	10.88	7.7	9.6	1.520	0.545	1.450	1.995	0.202	0.357	166
10/27/2003	12:50	12.98	9.02	4.6	5.8	2.200	0.517	1.400	1.917	0.003	0.366	144
10/27/2003	13:20	11.82	11.82	13.9	15.3	1.720	0.646	0.964	1.610	0.167	0.289	104
10/27/2003	13:50	11.66	11.66	6.8	8.5	2.340	0.753	1.880	2.633	0.311	0.420	106
Storm Event #2												
12/17/2003	08:50	82.32	29.30	8.5	10.4	3.040	0.682	6.790	7.472	0.157	1.160	143
12/17/2003	09:20	26.50	13.80	5.3	6.3	4.520	0.732	4.880	5.612	0.129	0.630	86
12/17/2003	09:50	29.60	15.40	6.0	8.2	1.650	0.820	4.900	5.720	0.004	0.632	91
12/17/2003	10:20	20.80	14.30	6.7	9.1	3.530	0.842	4.670	5.512	0.019	0.645	73
12/17/2003	10:50	42.40	23.70	7.3	11.3	2.940	1.200	5.910	7.110	0.004	0.883	106
12/17/2003	11:20	82.05	82.05	21.4	25.5	1.150	1.140	6.810	7.950	0.341	0.909	64
Storm Event #3												
11/4/2004	13:25	26.82	13.58	20.1	22.6	4.340	0.460	23.200	23.660	0.007	3.400	553
11/4/2004	13:55	30.00	13.70	16.0	23.2	3.080	0.463	12.300	12.763	0.210	1.650	189
11/4/2004	14:25	29.50	12.96	15.6	20.0	2.780	0.506	10.600	11.106	0.182	1.130	181
11/4/2004	14:55	24.36	13.40	14.6	21.5	3.140	0.430	12.600	13.030	0.274	1.470	122
11/4/2004	15:25	20.70	12.40	16.7	21.2	3.050	0.533	11.200	11.733	0.605	1.480	128
11/4/2004	15:55	23.50	12.80	20.9	25.2	2.800	0.630	10.300	10.930	0.644	1.320	104
Event Mean Concentrations												
EMC		28.25	17.97	12.51	15.84	2.828	0.693	7.274	7.966	0.220	1.041	160

Table 2-1d. Event mean concentrations for CSOs other than CSO 3, 4b, and 25

Date	Time	CBOD20 mg/L	CBOD5 mg/L	DOC mg/L	TOC mg/L	NH3-N mg/L	NOxN mg/L	TKN mg/L	TN mg/L	DOrthP mg/L	TP mg/L	TSS mg/L
STORET code –>		80087	80082	00681	00680	00610	00630	00625	****	00671	00665	00530
Event Mean Concentrations												
EMC*		18.79	12.33	13.73	15.68	0.596	0.772	2.025	2.796	0.339	0.473	61

*EMC is calculated as arithmetic mean of combined data from CSO 4b and CSO 25

2.3 Modeling Assumptions

The simulation of streamflow in the Christina River Basin HSPF models considered the following assumptions: (1) inputs of hourly precipitation would be estimated reasonably well by disaggregated 24-hour precipitation data; (2) the average precipitation over a given land segment would be represented adequately by weighted data from a single precipitation gage; and (3) a simplified set of impervious land uses (PERLND) and impervious land uses (IMPLND) would not limit a satisfactory hydrologic calibration (Senior and Koerkle, 2003a).

The simulation of water quality in the HSPF models considered the following assumptions: (1) land-based contributions of sediment and nutrients could be simulated by a simplified set of land-use categories; (2) water quality could be represented by the condition where chemical transformation of nutrients are simulated explicitly in the stream channel but not in land processes; and (3) the contribution of sediment from bank erosion in the stream channel can be estimated by sediment from pervious land areas (Senior and Koerkle, 2003a).

The simulation of CSO nutrient loads assumes that the event mean concentrations (EMCs) are the same no matter what the intensity or duration of the storm event. Nutrient concentrations were monitored only at three locations (CSO 4b, CSO 25, and 11th Street Pumping Station). The EMCs for CSO 3, which is located at the 11th Street Pumping Station, were calculated from the measurements at the 11th Street Pumping Station. The parameter EMCs for the remaining 35 CSO outfalls were assumed to be equivalent to the mean concentration of the combined storm monitoring data at CSO 4b and CSO 25.

2.4 HSPF Model Configuration

2.4.1 HSPF Subbasins

Four separate HSPF models were developed to simulate watershed runoff and nutrient loading in the Christina River Basin. One model was developed for each of the four main watersheds: Brandywine Creek watershed, White Clay Creek watershed, Red Clay Creek watershed, and Christina River watershed. The Christina River Basin was delineated into 70 subbasins (or reaches) for the modeling effort (see Figure 1-1). The size of the subbasins ranged from 0.6 to 25.5 mi^2. The subbasins were delimited based on major tributary inflows, calibration locations (stream gages and water quality monitoring stations), and time-of-travel considerations.

2.4.2 Land Use Classifications

Spatial data input to the HSPF model are used to define the structure fixed characteristics of the model. The principal structural unit of the HSPF model is the hydrologic response units PERLND (pervious land) and IMPLND (impervious land). Fifteen original land-use categories (circa 1995) from several sources were simplified and reclassified into ten pervious and two impervious land-use categories that were expected to have distinct nonpoint-source water-quality characteristics (Table 2-2).

Agricultural land use was divided into three characteristic subtypes for the model. Agricultural-livestock land use identifies relatively small acreage farms with high animals-per-acre densities, limited pasture areas, and rowcrops. Small acreage dairy operations typify this land-use type. Agricultural-rowcrop land use identifies farms with lower animals-per-acre densities (typically beef cattle and horses) and substantial pasture and crop acreage. Agricultural-mushroom land use is the third type of agriculture land use delimited, but mushroom production operations are much more prevalent in the Red Clay Creek and White Clay Creek Basins than in the Brandywine Creek Basin. Residential land use is distributed throughout the basin and is divided into two types: sewered and non-sewered. Sewered residential areas tend to have higher housing densities and are nearer to urban/suburban areas than non-sewered area. Non-sewered residential areas tend to have lower densities and are more rural. Other urban land use is in small boroughs and along major roadways. Forested land is distributed throughout the basin and tends to be along stream channels. The land use delineations for each of the four main watersheds in the Christina River Basin are presented in Tables 2-3 through 2-6.

Table 2-2. Land-use categories used in HSPF models for Christina River Basin

Land-use category for HSPF model		Description
Pervious	Residential-septic	Residential land not within a sewer service area
	Residential-sewer	Residential land within a sewer service area
	Urban	Commercial, industrial, institutional, and transportation uses
	Agricultural-livestock	Predominantly mixed agricultural activities of dairy cows, pasture, and other livestock operations
	Agricultural-rowcrop	Predominantly row crop cultivation (corn, soybean, alfalfa), may include some hay or pasture land
	Agricultural-mushroom	Mushroom-growing activities including compost preparation, mushroom-house operations, spent compost processing
	Open	Recreational and other open land not used for agricultural
	Forested	Predominantly forested land
	Wetlands/water	Wetlands and open water
	Undesignated	Land use not defined
Impervious	Residential	Impervious residential land
	Urban	Impervious commercial, industrial, and other urban land

Table 2-3. Land use characteristics (in percent) for Brandywine Creek Watershed.

Reach	Length (mi)	Area (sq.mi.)	Resident. Septic	Resident. Sewer	Urban	Agriculture livestock	Agriculture row crop	Agriculture mushroom	Forested	Open	Wetland-water	Undesig-nated	Impervious-residential	Impervious-urban
1	6.60	18.39	4.1	1.4	0.6	45.6	22.5	0.0	20.1	2.7	0.5	0.9	1.1	0.7
2	7.60	7.38	17.3	0.6	1.8	9.4	19.0	0.0	46.4	0.5	0.8	0.2	2.2	1.8
3	2.94	6.76	22.3	0.3	1.2	7.5	22.6	0.0	39.8	2.0	0.5	0.0	2.6	1.2
4	1.85	0.80	0.0	7.1	2.1	0.0	14.9	0.0	68.8	0.1	1.7	0.2	3.0	2.1
5	2.91	8.82	1.5	11.0	10.5	0.0	19.1	0.0	34.8	3.6	1.5	2.4	4.9	10.7
6	2.93	8.06	17.1	0.5	1.5	4.0	35.6	0.0	35.4	1.8	0.5	0.0	2.1	1.5
7	7.80	13.46	5.9	0.0	1.5	0.0	49.0	0.0	38.2	1.9	1.2	0.1	0.7	1.5
8	2.19	3.62	9.2	0.0	0.6	0.0	62.6	0.0	24.9	0.0	1.2	0.1	1.0	0.6
9	7.10	14.68	6.1	0.5	0.4	27.0	27.0	0.0	32.6	2.2	2.8	0.2	0.9	0.4
10	12.10	18.31	17.0	0.2	1.2	0.0	36.0	0.0	40.3	1.2	0.6	0.2	2.0	1.2
11	1.79	6.31	4.7	11.6	1.9	0.0	33.1	0.0	35.6	4.7	0.5	0.6	5.5	1.9
12	2.02	3.70	8.4	18.7	4.4	0.0	11.4	0.0	38.9	2.2	1.3	1.3	8.9	4.5
13	3.86	7.94	6.5	10.1	4.3	0.0	14.3	0.0	47.9	3.1	1.4	2.7	5.1	4.6
14	4.86	12.92	8.8	10.8	3.5	0.0	31.9	0.0	30.2	3.2	1.0	1.4	5.6	3.6
15	2.49	10.36	17.6	7.2	1.9	0.0	40.7	0.0	16.8	6.9	1.0	1.0	5.0	1.9
16	2.88	14.06	25.0	0.0	2.4	0.0	25.7	0.0	38.7	1.6	0.9	0.5	2.8	2.4
17	4.15	7.51	12.2	0.0	0.1	0.0	27.0	0.0	48.6	6.1	1.3	0.4	4.1	0.3
18	3.39	10.37	9.2	3.5	1.6	2.1	19.1	0.0	38.2	14.6	1.1	5.8	2.5	2.2
19	2.71	8.64	10.6	10.3	3.4	0.0	4.1	0.0	16.5	40.3	1.0	4.6	5.6	3.6
20	8.66	25.54	7.7	1.8	1.1	5.9	52.9	0.0	25.5	1.3	0.4	0.8	1.6	1.1
21	6.73	11.05	3.5	0.0	0.4	7.6	68.6	0.0	17.3	1.1	0.1	0.5	0.4	0.4
22	3.18	10.96	0.7	0.0	0.9	7.9	71.3	0.0	17.7	0.0	0.3	0.2	0.1	0.9
23	0.87	1.95	0.0	0.0	0.01	4.9	44.4	0.0	49.4	0.0	1.3	0.0	0.0	0.01
24	3.14	0.60	73.2	4.9	0.0	0.0	3.5	0.0	8.2	0.0	0.0	0.0	10.3	0.0
25	3.14	5.83	15.2	3.7	2.3	0.0	40.7	0.0	30.4	1.7	0.1	0.3	3.3	2.3
26	1.60	2.61	8.1	0.0	2.2	6.5	19.6	0.0	59.5	0.3	0.5	0.1	0.9	2.2
27	4.80	11.54	21.5	0.1	0.9	8.9	20.6	0.0	33.9	2.4	7.4	1.1	2.4	0.9
28	2.00	2.40	0.1	37.6	6.5	0.0	3.0	0.0	20.5	5.7	0.0	3.6	16.1	6.7
29	7.20	18.21	4.3	12.9	3.5	0.0	20.9	0.0	35.1	5.0	2.5	3.2	6.0	6.7
30	4.09	18.08	12.2	6.6	4.7	0.0	32.4	0.0	30.0	2.2	0.2	2.7	4.2	5.0
31	4.09	9.19	22.7	0.0	0.8	0.0	48.8	0.0	22.1	1.8	0.3	0.3	2.5	0.8
32	2.00	4.66	11.3	0.0	0.8	15.8	15.8	0.0	52.9	0.9	0.1	0.3	1.3	0.8
33	2.75	8.03	12.2	3.5	1.3	4.2	38.0	0.0	29.8	4.5	2.1	0.4	2.9	1.3
34	4.46	6.05	1.9	2.5	28.0	0.0	1.6	0.0	13.9	12.9	2.6	7.3	1.3	28.2
35	4.00	5.80	6.3	0.0	1.1	12.1	36.3	0.0	34.1	0.3	7.8	0.2	0.7	1.1
Total	144.88	324.59	10.5	3.9	2.7	6.3	32.7	0.0	31.8	3.8	1.2	1.3	2.9	2.8

Table 2-4. Land use characteristics (in percent) for White Clay Creek watershed.

Reach	Length (mi)	Area (sq.mi.)	Resident. Septic	Resident. Sewer	Urban	Agriculture livestock	Agriculture row crop	Agriculture mushroom	Forested	Open	Wetland-water	Undesig-nated	Impervious-residential	Impervious-urban
1	7.33	10.23	15.6	0.0	1.0	10.4	36.2	5.2	26.1	2.1	0.1	0.7	1.8	1.0
2	6.57	9.51	11.3	1.8	0.8	15.9	47.5	0.0	17.7	1.1	0.2	0.9	2.0	0.8
3	7.18	6.35	16.4	0.0	0.0	9.0	33.5	2.2	35.9	0.6	0.5	0.0	1.9	0.0
4	6.02	6.20	6.8	2.6	1.3	11.5	40.2	5.8	23.5	2.4	0.5	2.1	1.9	1.5
5	2.49	2.65	1.5	0.0	0.0	14.7	52.1	7.5	23.0	0.8	0.0	0.4	0.0	0.0
6	6.16	8.57	1.5	0.8	1.3	13.4	47.3	6.8	21.8	2.9	0.2	2.1	0.5	1.3
7	1.75	1.37	5.8	5.1	1.5	0.0	5.8	56.2	17.5	0.0	1.5	2.9	2.9	1.5
8	4.09	7.47	11.6	0.5	0.5	0.0	20.1	30.3	32.4	1.2	0.5	0.8	1.5	0.5
9	4.46	6.85	17.5	7.2	0.7	6.6	22.9	3.2	31.7	2.3	1.6	0.6	5.0	0.7
10	1.67	3.58	11.2	4.5	0.0	5.3	21.8	0.0	53.1	0.3	0.6	0.3	3.1	0.0
11	4.02	6.53	1.2	8.1	4.3	0.0	15.5	0.0	54.8	7.0	0.8	0.3	3.7	4.3
12	5.28	8.76	0.0	24.1	10.2	0.0	9.4	0.0	10.7	9.8	0.9	10.2	10.4	14.4
13	2.21	2.08	0.0	6.7	14.4	0.0	11.1	0.0	11.5	7.2	1.4	27.4	2.9	17.3
14	2.97	3.41	0.0	10.6	11.4	0.0	0.0	0.0	14.1	21.7	14.4	10.6	4.7	12.6
15	4.08	3.89	0.0	14.4	1.8	0.0	29.6	0.0	42.2	3.3	0.0	0.5	6.2	2.1
16	5.85	6.65	0.0	38.9	6.2	0.0	8.4	0.0	12.9	9.2	0.0	1.4	16.7	6.3
17	9.76	13.00	0.5	33.9	6.6	1.1	8.7	1.1	11.7	10.2	0.0	4.1	15.1	7.1
Total	81.89	107.10	6.5	11.1	3.4	5.8	25.3	4.9	24.8	4.9	0.9	2.9	5.5	4.0

Table 2-5. Land use characteristics (in percent) for Red Clay Creek watershed

Reach	Length (mi)	Area (sq.mi.)	Resident. Septic	Resident. Sewer	Urban	Agriculture livestock	Agriculture row crop	Agriculture mushroom	Forested	Open	Wetland-water	Undesig-nated	Impervious-residential	Impervious-urban
1	5.00	10.08	10.4	1.6	2.1	5.9	46.8	5.9	18.4	2.8	0.4	1.6	1.9	2.2
2	4.90	7.39	11.8	0.5	0.7	0.0	40.9	17.5	25.2	0.3	0.2	0.7	1.5	0.7
3	7.20	9.90	14.9	1.9	1.0	0.0	33.1	14.2	22.5	5.8	0.6	2.3	2.5	1.1
4	3.40	5.11	35.5	2.3	1.0	1.8	14.2	1.8	28.4	7.9	0.8	0.6	4.9	1.0
5	5.10	5.24	32.2	2.2	0.2	0.0	14.6	0.0	37.7	6.0	1.2	0.9	4.6	0.2
6	5.00	7.10	23.9	0.0	0.2	0.0	42.4	0.0	25.1	5.1	0.1	0.3	2.7	0.2
7	1.70	2.10	26.1	0.0	0.5	0.0	7.2	0.0	44.4	3.0	14.3	1.1	2.9	0.5
8	4.30	5.38	1.5	35.3	5.3	0.0	1.6	0.0	13.4	13.8	1.4	6.3	15.3	6.0
9	0.84	1.72	0.0	45.5	4.8	0.0	0.0	0.0	10.2	3.8	0.4	9.9	19.5	5.9
Total	37.44	54.02	17.1	6.1	1.6	1.3	29.2	6.3	24.0	5.2	1.2	2.0	4.5	1.7

Table 2-6. Land use characteristics (in percent) for Christina River watershed

Reach	Length (mi)	Area (sq.mi.)	Resident. Septic	Resident. Sewer	Urban	Agriculture livestock	Agriculture row crop	Agriculture mushroom	Forested	Open	Wetland-water	Undesig-nated	Impervious-residential	Impervious-urban
1	1.46	1.87	9.1	0.0	0.4	0.0	58.1	0.0	29.7	1.1	0.0	0.2	1.0	0.4
1	3.33	4.83	7.9	4.0	7.9	0.0	27.1	0.0	23.4	12.5	0.0	6.2	2.6	8.3
2	4.96	7.08	25.5	4.7	0.3	0.0	41.1	0.0	21.7	0.6	0.1	1.0	4.8	0.3
2	3.20	2.65	7.7	25.9	9.6	0.0	4.5	0.0	10.7	13.8	0.0	13.3	12.0	10.2
3	3.24	4.47	4.8	17.5	12.7	0.0	9.2	0.0	18.4	8.0	0.2	9.0	8.0	13.5
4	4.65	5.37	1.5	28.1	12.8	0.0	1.4	0.0	18.3	9.2	0.2	2.6	12.2	13.4
5	2.30	3.84	0.1	20.9	17.6	0.0	0.0	0.0	8.7	15.2	1.1	9.3	8.9	25.6
6	6.73	8.64	6.0	8.8	6.6	0.0	15.5	0.0	38.4	10.6	1.1	1.8	4.5	6.8
7	2.08	6.37	0.6	20.1	6.9	0.0	8.5	0.0	34.3	8.1	0.8	4.7	8.7	7.4
8	6.21	10.70	0.2	19.3	8.4	0.0	10.4	0.0	27.0	7.0	0.5	9.3	8.3	9.2
9	15.09	21.90	0.5	10.3	17.8	0.0	1.8	0.0	12.5	20.0	4.3	9.9	4.5	18.5
Total	53.25	77.70	4.6	13.7	10.8	0.0	11.9	0.0	21.6	11.6	1.6	6.5	6.4	11.4

2.4.3 Nutrient Sources

The HSPF models required large amounts of data to characterize the hydrologic and water quality response of the watershed to precipitation and other inputs. Data used in creating the model structure and parameters were derived primarily from spatial analysis of basin characteristics and other published information. Spatial data analyzed for model construction included land use, land-surface slope, and soil associations. Time-series inputs for streamflow and water-quality simulation included meteorologic, precipitation quality, water-use, and point source quantity and quality data. Nonpoint sources of nutrients were calculated by the model based on build up, storage, and wash off processes inherent in the HSPF model.

2.4.4 Time Step and Simulation Duration

The HSPF models were executed on a 1-hour time step. The duration of the calibration runs was from October 1, 1994 to October 1, 1998, a period that covered four consecutive water years.

2.5 Model Testing and Calibration

Complete descriptions of the calibration of each of the four HSPF models for the Christina River Basin can be found in the USGS Water Resources Investigation Reports (Senior and Koerkle, 2003a, 2003b, 2003c, and 2003d), which are available in Portable Document File (PDF) format at the following website: http://pa.water.usgs.gov/pa_pubs.html